X-636-64-253
TM X-55098

POST IRRADIATION ROOM TEMPERATURE ELECTRICAL CHARACTERISTICS OF N/P SILICON SOLAR CELLS

BY
BRIAN T. CUNNINGHAM
AND
ERNEST MOSS

AUGUST 1964

NASA

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

POST-IRRADIATION, ROOM TEMPERATURE, ELECTRICAL CHARACTERISTICS OF N/P SILICON SOLAR CELLS

By

Brian T. Cunningham

and

Ernest Moss

August 1964

TABLE OF CONTENTS

INTRODUCTION

An engineering investigation has been conducted to determine the post-irradiation, room temperature electrical characteristics of state-of-the-art, flight-quality, silicon N/P solar cells. The primary reason for this work was to obtain a complete and up-to-date evaluation of flight-quality solar cells being produced by the leading solar cell manufacturers in the United States. The present report contains the results of a 1 Mev electron bombardment to a flux level of 10^{16} electrons/cm^2 conducted at, or near, room temperature, combined with a cursory examination of post-irradiation annealing at elevated temperatures.

PROCEDURE

A "Request for Quotations" was forwarded in April 1964 to each of the leading solar cell manufacturers, requesting price information on production-type, flight-quality, 1×2 cm N/P solar cells in various quantities and efficiencies. The results of this request are shown in Table I. An order was placed with each of the respondents for 50 of the highest efficiency cells which they quoted in the RFQ. A tabulation of the purchase order is shown in Table I. It should be noted that no particular requirement was placed on base resistivity and hence the cells received varied from a nominal 1 to a nominal 10 ohm-cm material. Base resistivity ranges are given in Table IV. Nominal values are used throughout this presentation. In addition to the boron-doped cells received from all manufacturers, a group of 15 aluminum-doped 10 ohm-cm cells were forwarded by the Texas Instruments Company.

Table I

Summary of Cell Efficiency Order

Manufacturer	AMO Efficiency
Heliotek	11%
Hoffman	11%
International Rectifier	10.5%
Texas Instruments	10.5%
Radio Corporation of America	13%

Twenty-five cells from each manufacturer (with the exception of the aluminum-doped cells, where only fifteen were available) were selected at random for irradiation. E-I curves for all cells were obtained using a Spectrosun solar simulator. The simulator intensity was adjusted to an air mass zero equivalent with an aircraft-calibrated solar cell.* All measurements in this report were made at 32°C ± 2° as measured on a thermocouple placed underneath the thermally conductive cell-mounting block. In the data to be presented, it will be noted that the results have been normalized to 30° centigrade, using results obtained previously.[1]

After initial measurements were made, the cells were taken to the Naval Research Laboratory in Washington, D. C. for irradiation on the 1 Mev Van de Graaff generator. After each dose the cells were returned to the Goddard Space Flight Center for measurements.

*The calibrated solar cells were flown at different altitudes by the Lewis Research Center. A Langley plot was made of short circuit current vs. air mass and the extrapolated air mass zero short circuit current obtained.

Each group of 25 cells (again with the exception of the aluminum-doped units, where three were pulled after each irradiation) was allocated as shown in Table II.

Table II

Typical Allocation of Solar Cells from Each Manufacturer

1 Mev Flux Electrons/cm^2	Number of Cells Irradiated	Number of Cells Withheld	Temperature Treatment
5×10^{12}	25	4	4
5×10^{13}	21	4	4
5×10^{14}	17	4	4
5×10^{15}	13	4	4
10^{16}	9	-	4

It may be seen from this table that after each irradiation, four cells were removed from the group for the purpose of more extensive tests to be conducted later. Four cells from each manufacturer (noted in the column labeled Temperature Treatment) were measured after the irradiation, given a temperature cycle later modified to a high temperature soak—and then immediately remeasured. These cells were then subjected to the next irradiation. The same group of cells was temperature-cycled throughout the experiment. No thermal tests were conducted on the aluminum-doped cells because of the limited number available. The post-irradiation measurement and thermal treatment schedule are shown in Table III.

Table III

Measurement and Heat Treatment Schedule

1 Mev Flux (electrons/cm^2)	Nontreated Cells Post-Irradiation Measurement Commenced after (hours)	Treated Cells Post-Irradiation Measurement Commenced after (hours)	Temperature Treatment
5×10^{12}	18	1	A
5×10^{13}	1	1	B
5×10^{14}	1	1	C
5×10^{15}	18	1	D
10^{16}	18	18	E

Explanation of Temperature Treatment:

A – Room temperature to -70°C to 100°C in 1 hour, hold at 100°C for 0.5 hour.

B – Same as A except temperature was held 100°C for 2 hours.

C – Room temperature to 100°C in 0.25 hour, hold at 100°C for 2 hours.

D – Same as C except cells were held for 4 hours at 100°C.

E – Same as C except cells were held at 100°C for 3 hours.

After the temperature treatment, the cells were allowed to cool to room temperature before measurements commenced.

RESULTS

Average values have been used throughout the data presentation because of the small amount of scatter and the convenience associated with data reduction.

Results of the initial (pre-irradiation) measurements are shown in Table IV.

Table IV

Initial Comparison of Manufacturer's Cells

Manufacturer	Code Letter	Average Maximum Power (MW)	Average AMO Efficiency* (%)	**Base Resistivity Range (ohm-cm)		
				Low	Nominal	High
Heliotek	A	24.9	9.9%	7	10	14
Hoffman	B	25.3	10.0%	8	10	12
RCA	C	26.7	10.6%	0.7	1	1.2
TI (Boron)	D	25.7	10.2%	7	10	13
IRC	E	25.2	10.0%	?	2	?
TI (Aluminum)	F	24.5	9.7%	7	10	13

*Based on 1.8 cm^2 area
**According to manufacturer

Figure 1 depicts the change in short circuit current as a function of irradiation. It may be seen that in drawing the curves the data points were followed quite closely so as not to obscure any trends in the end points. Note the clear distinction between the lower (1 and 2 ohm-cm) and the higher (10 ohm-cm) base resistivity cells. Figure 2 shows the change in maximum power as a function of irradiation for all cells under investigation. Note that the TI cells show significantly less degradation than the other 10 ohm-cm cells, which in turn show significantly less degradation than the lower base resistivity cells. Figure 3 depicts the change in open circuit voltage as a function of irradiation. Figures 4 through 9 show the average E-I curve at different 1 Mev flux levels for each manufacturer. Figures 10 through 14 show the effect of thermal cycling. The smooth dashed curve in these figures is the same curve as appears in Figure 1 for the particular manufacturer. The solid sawtoothed degradation curve shows the effect of thermal cycling. The lower points at each flux level represent the average short circuit current readings of the cells prior to the thermal treatment described in the procedure. The upper value represents the post-thermal treatment average of the same cells.

CONCLUSIONS

1. Solar cell manufacturers are presently producing cells with a nominal 10% air mass zero efficiency.

2. The nominal 10 ohm-cm solar cell is decidedly more radiation resistant than the 1 ohm-cm cell at higher 1 Mev electron flux levels. This is apparent in both the short circuit current and the maximum power.

3. Both the boron and the aluminum-doped TI cells show less radiation degradation, particularly in the maximum power, than any of the other manufacturers' cells under investigation.

4. Differences in radiation degradation observed between the aluminum and the boron-doped TI cells were small and not considered significant.

5. Changes in short circuit current due to a post-irradiation temperature treatment (sometimes called annealing) were definitely experienced in a limited experiment and can be as much as 5%. Measurements were not extensive enough to determine quantitatively how much of an effect the elevated temperature had on I_{sc} change; however, as noted in Table III, after the 10^{16} electrons/cm^2 dose, the cells were allowed to sit at room temperature overnight before any measurements were made. The data in Figures 9 through 14 at the 10^{16} e/cm^2

flux level seem to indicate that an appreciable amount of improvement in I_{sc} (relative to the other post-irradiation, pre-heat treatment measurements) had taken place at room temperature in the intervening eighteen hours. The following general observations can be made relative to the change in I_{sc}:

A. Subsequent irradiations degrade the cell more rapidly so that the end result essentially is the same as if no I_{sc} improvement had taken place.

B. Cells from different manufacturers show different I_{sc} improvement characteristics.

   (1) Initial temperature cycling seems to have degraded the TI cells so that subsequent post-irradiation treatment did not bring the post-thermal treatment value above the average of the nontreated cells.

   (2) The low base resistivity (RCA and IRC) treated cells are consistently above the average degradation line.

   (3) The 10 ohm-cm Heliotek and Hoffman cells oscillate about the average line as a result of the temperature treatment.

C. In order to compare the results of radiation damage studies performed in the laboratory, it will be necessary to find a means of monitoring or quenching the I_{sc} change so as to normalize the results to a given time after irradiation.

ACKNOWLEDGMENTS

Mr. William R. Cherry and Mr. Luther W. Slifer, Jr. of GSFC for assistance in the planning of the experiments.

Mr. Carmen Carosella and Mr. Richard Statler of NRL for conducting the irradiation.

REFERENCE

1. Brian T. Cunningham, Robert L. Sharp, and Luther W. Slifer, Jr., The Electrical Characteristics of Irradiated Silicon Solar Cells as a Function of Temperature, NASA-Goddard Space Flight Center, Greenbelt, Md., March 30, 1964.

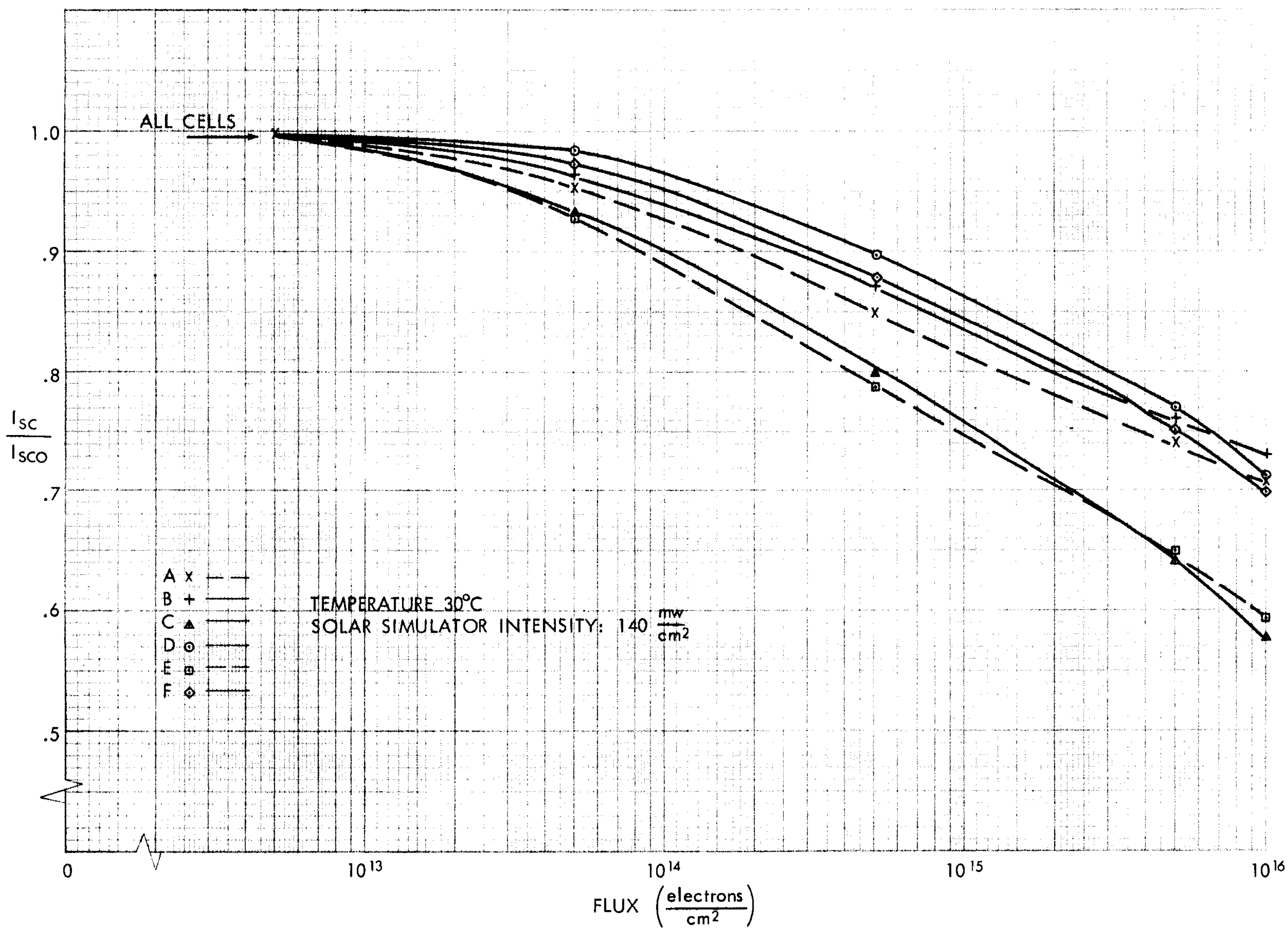

Figure 1 - Average Short Circuit Current Degradation as a Function of 1 Mev Electron Flux

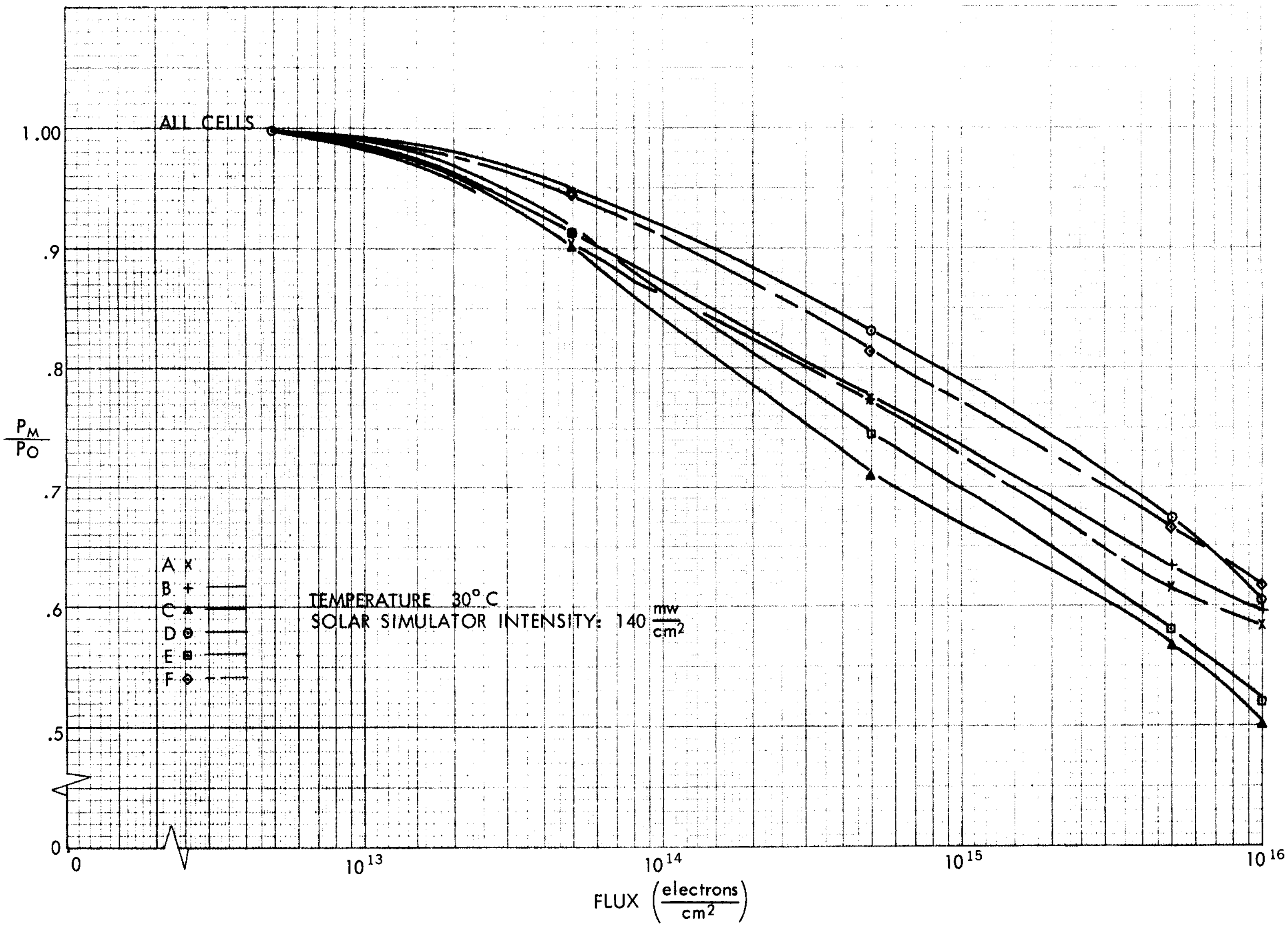

Figure 2 - Average Peak Power Degradation as a Function of 1 Mev Electron Flux

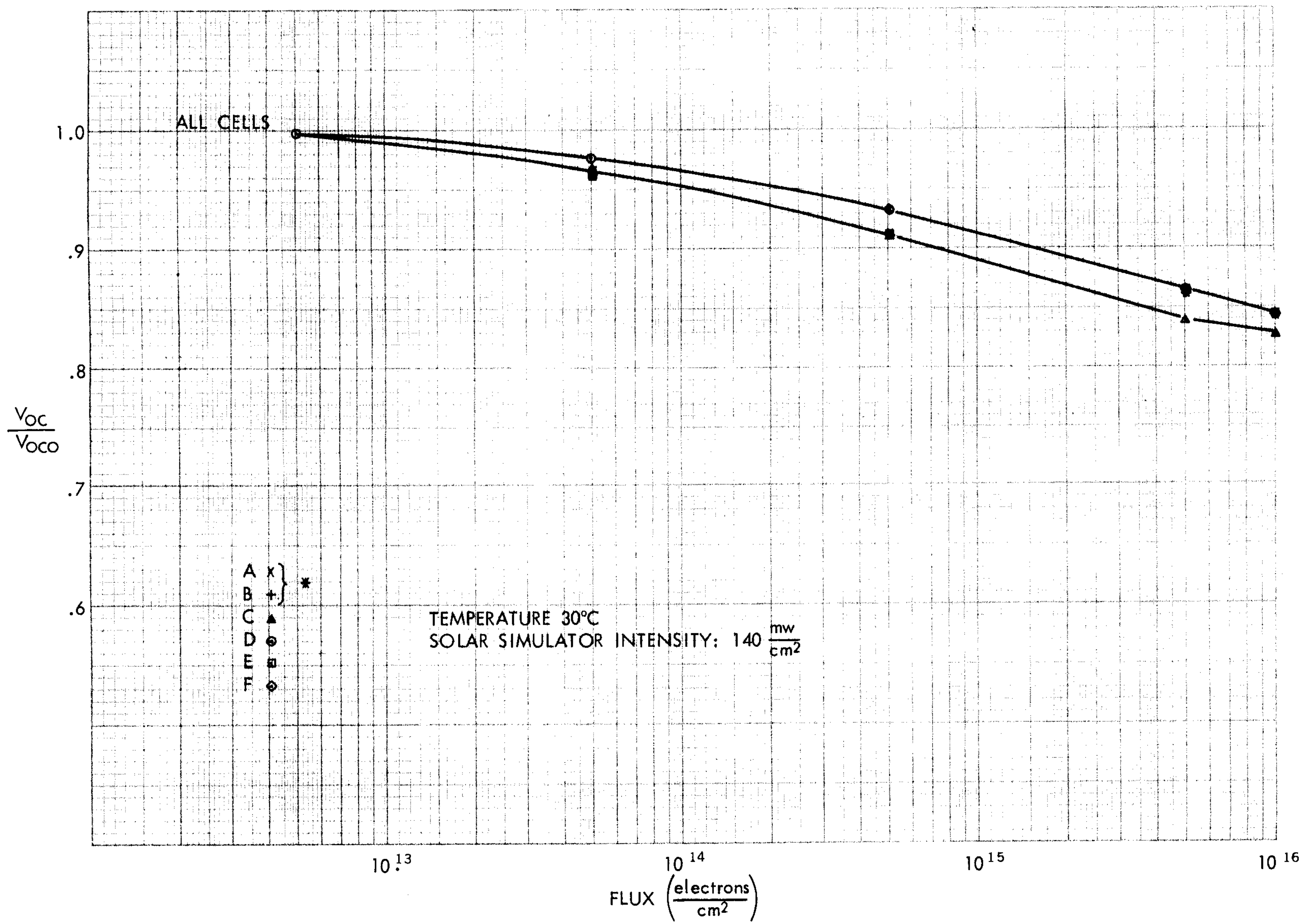

Figure 3 - Average Open Circuit Voltage Degradation as a Function of 1 Mev Electron Flux

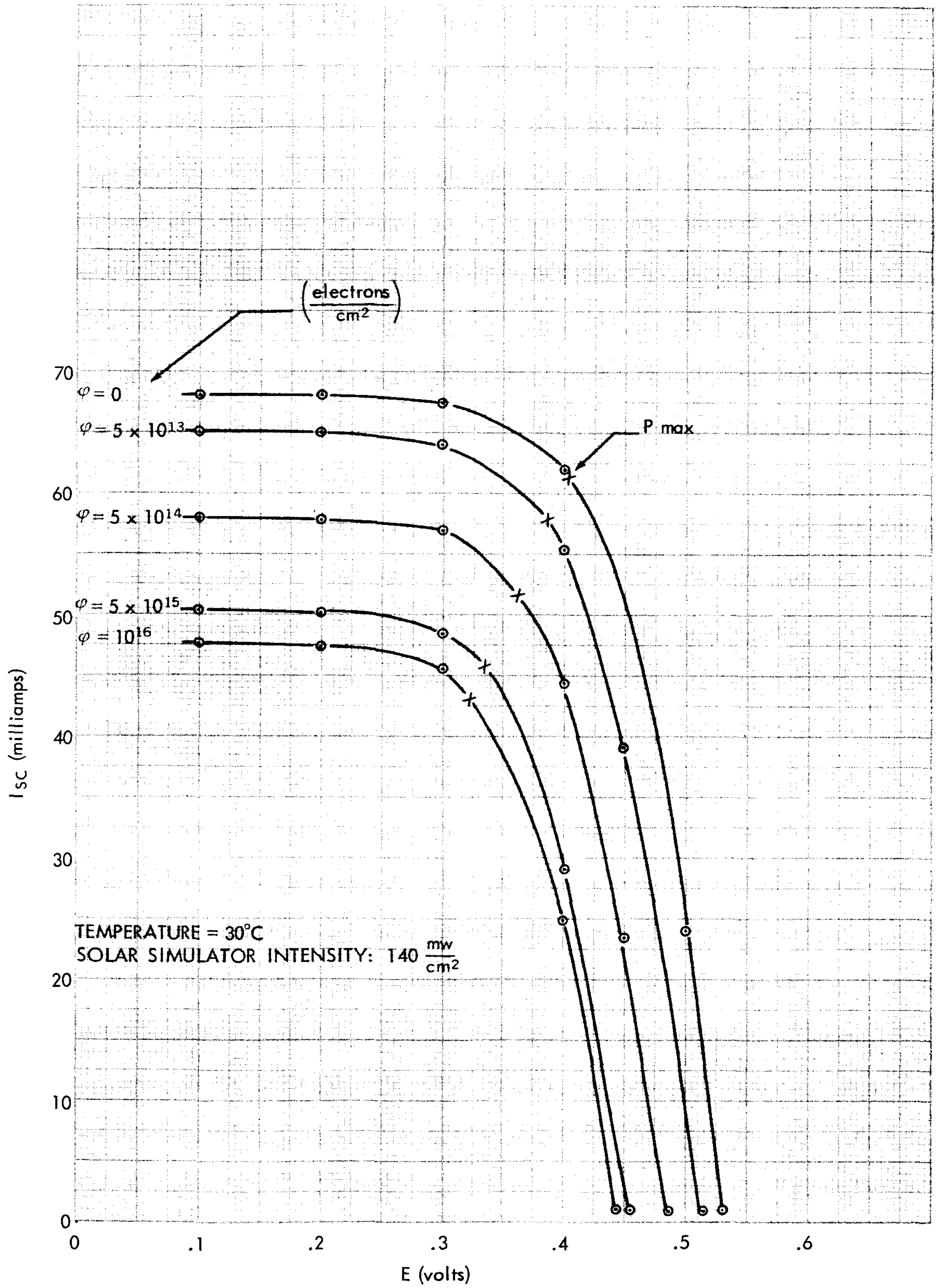

Figure 4 - Average Degradation of Group A Solar Cell I-V Curves with 1 Mev Electron Bombardment

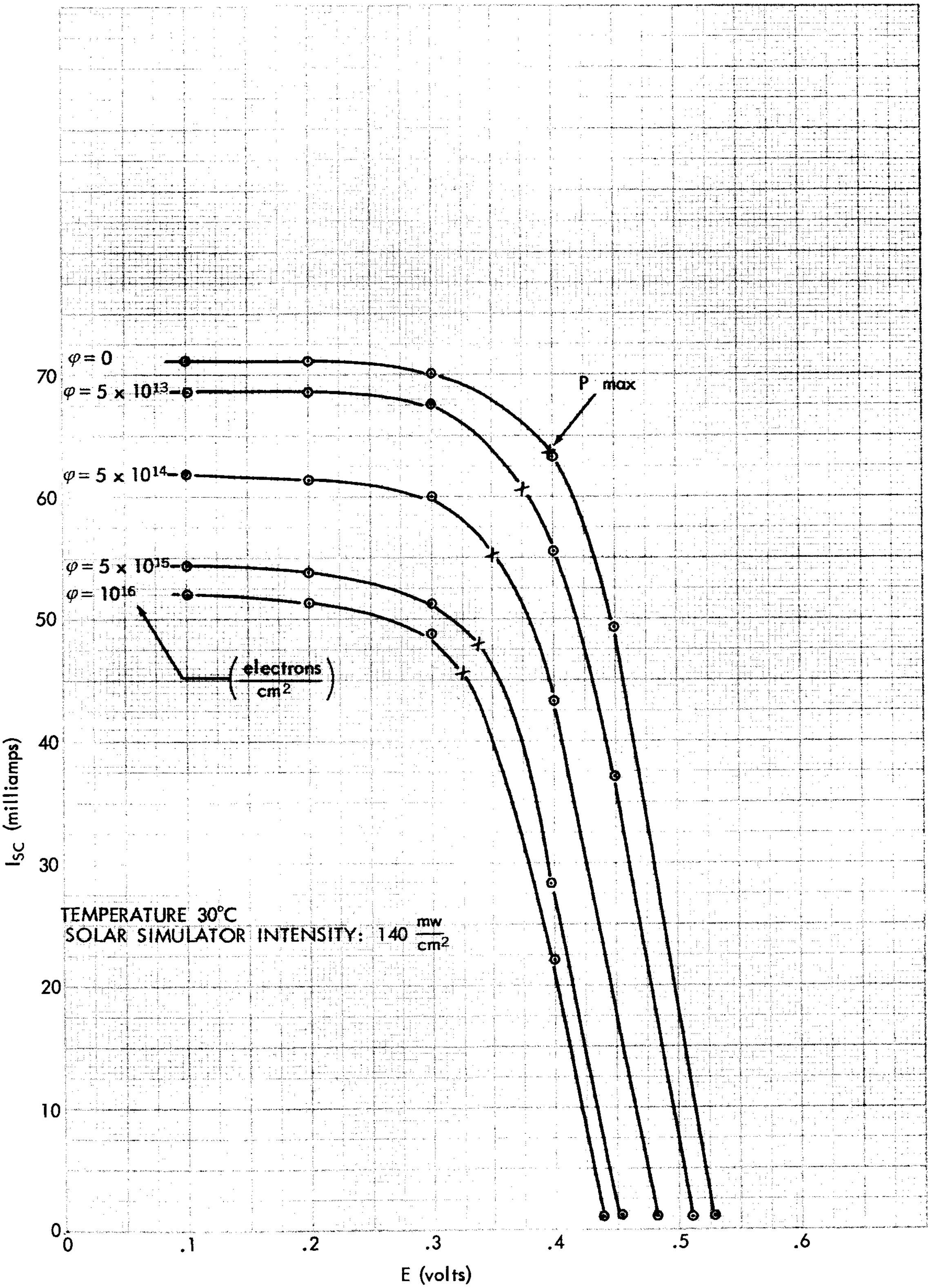

Figure 5 - Average Degradation of Group B Solar Cell I-V Curves with 1 Mev Electron Bombardment

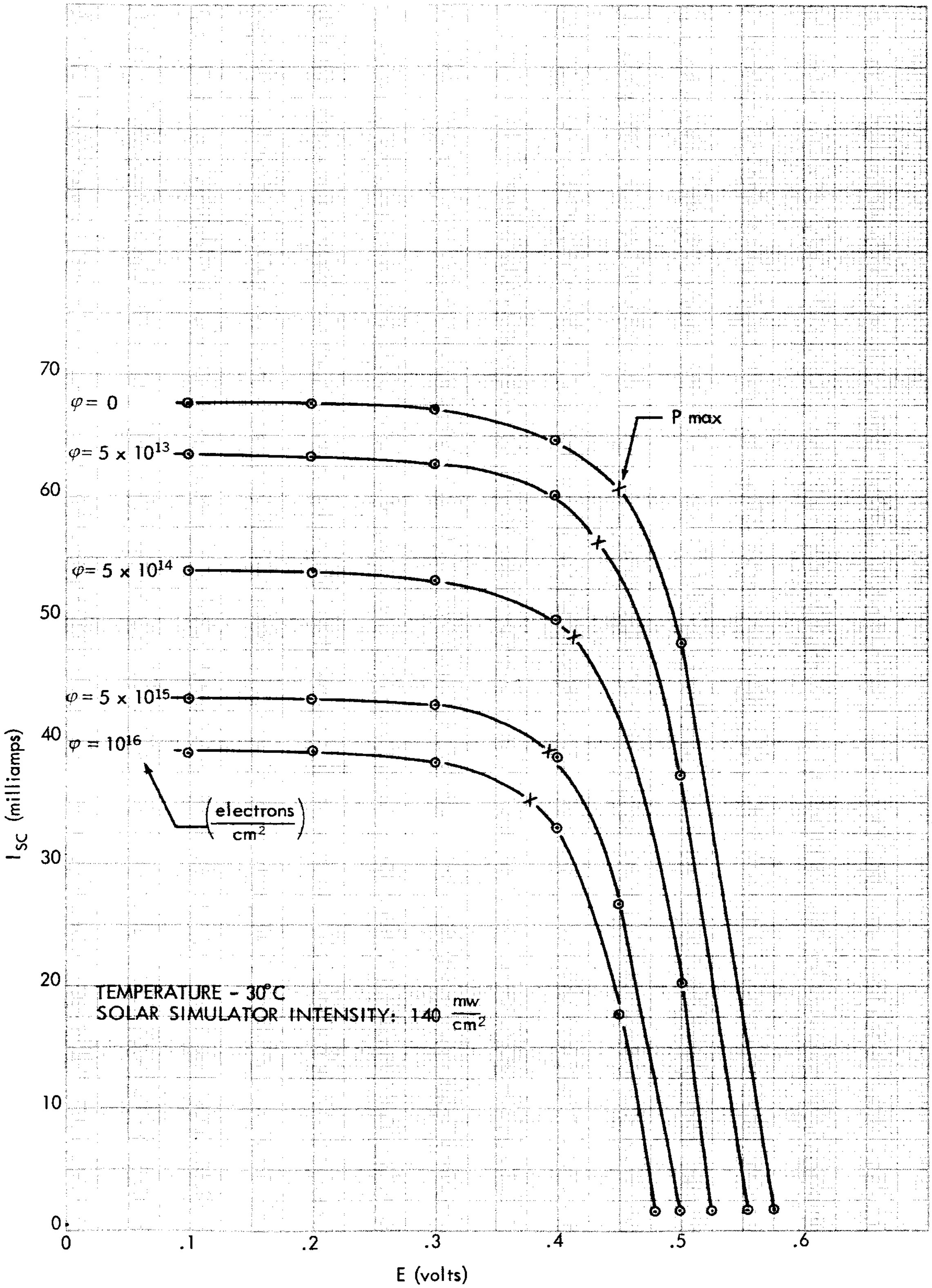

Figure 6 - Average Degradation of Group C Solar Cell I-V Curves with 1 Mev Electron Bombardment

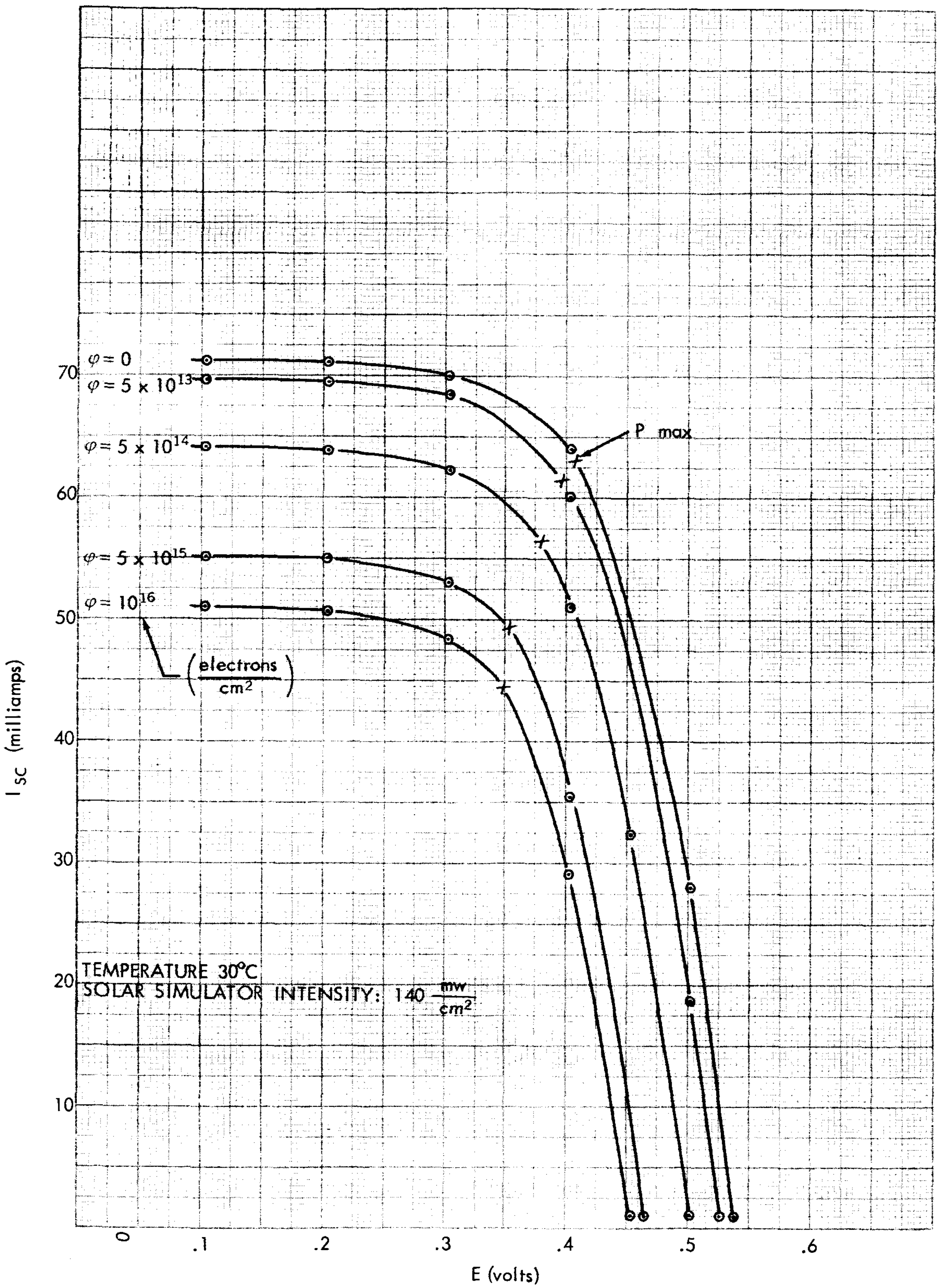

Figure 7 - Average Degradation of Group D Solar Cell I-V Curves with 1 Mev Electron Bombardment

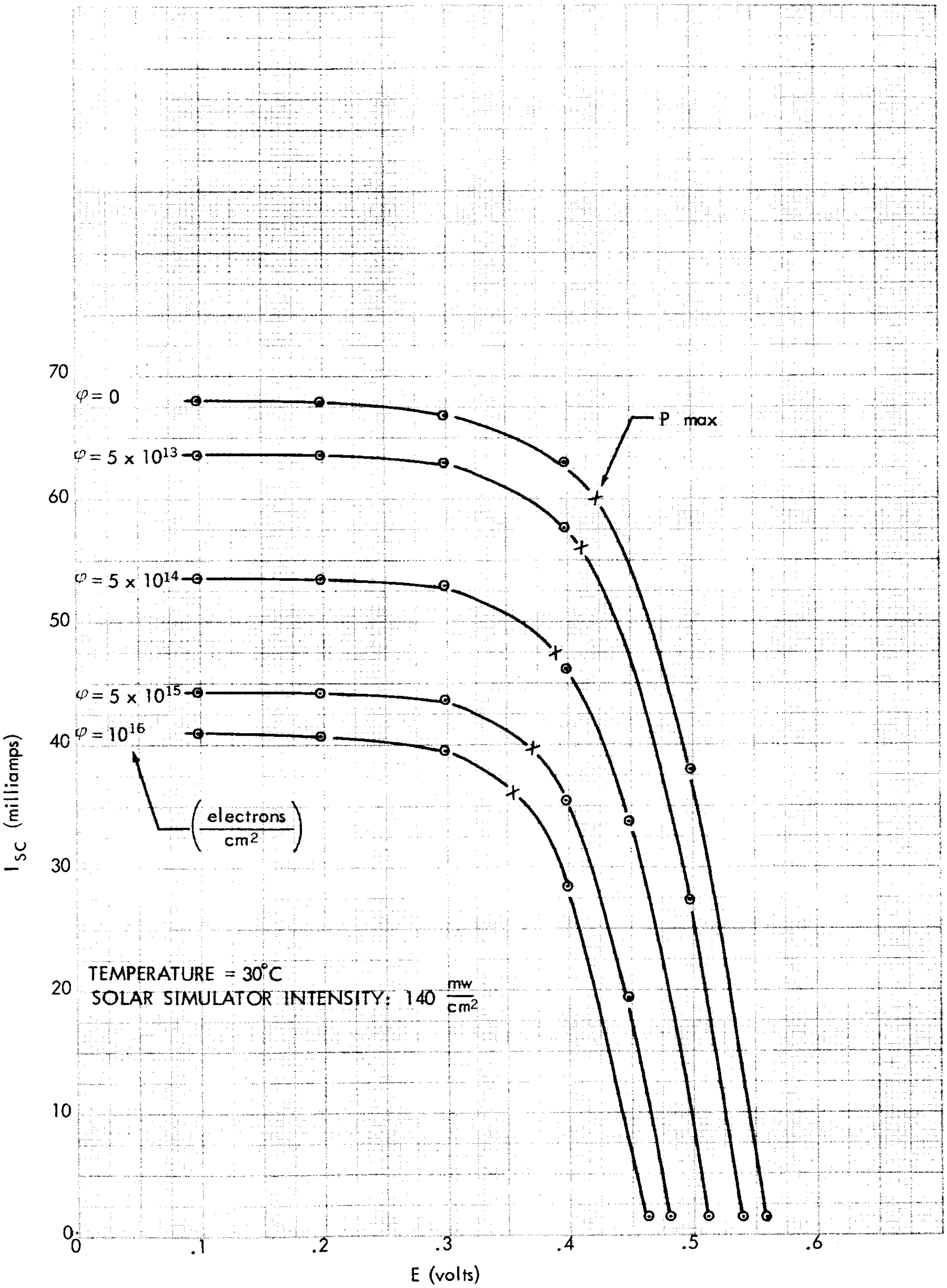

Figure 8 - Average Degradation of Group E Solar Cell I-V Curves with 1 Mev Electron Bombardment

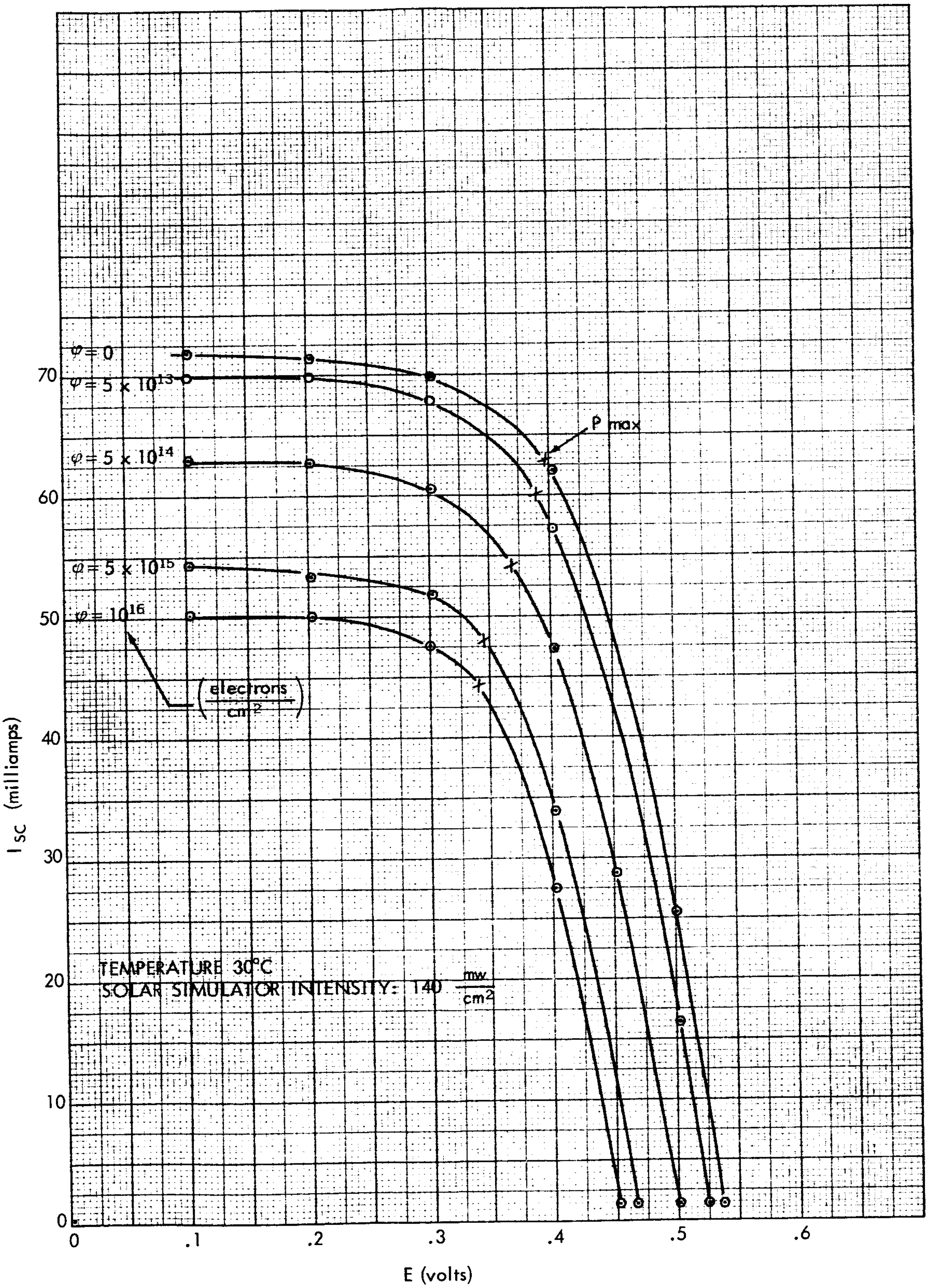

Figure 9 - Average Degradation of Group F Solar Cell I-V Curves with 1 Mev Electron Bombardment

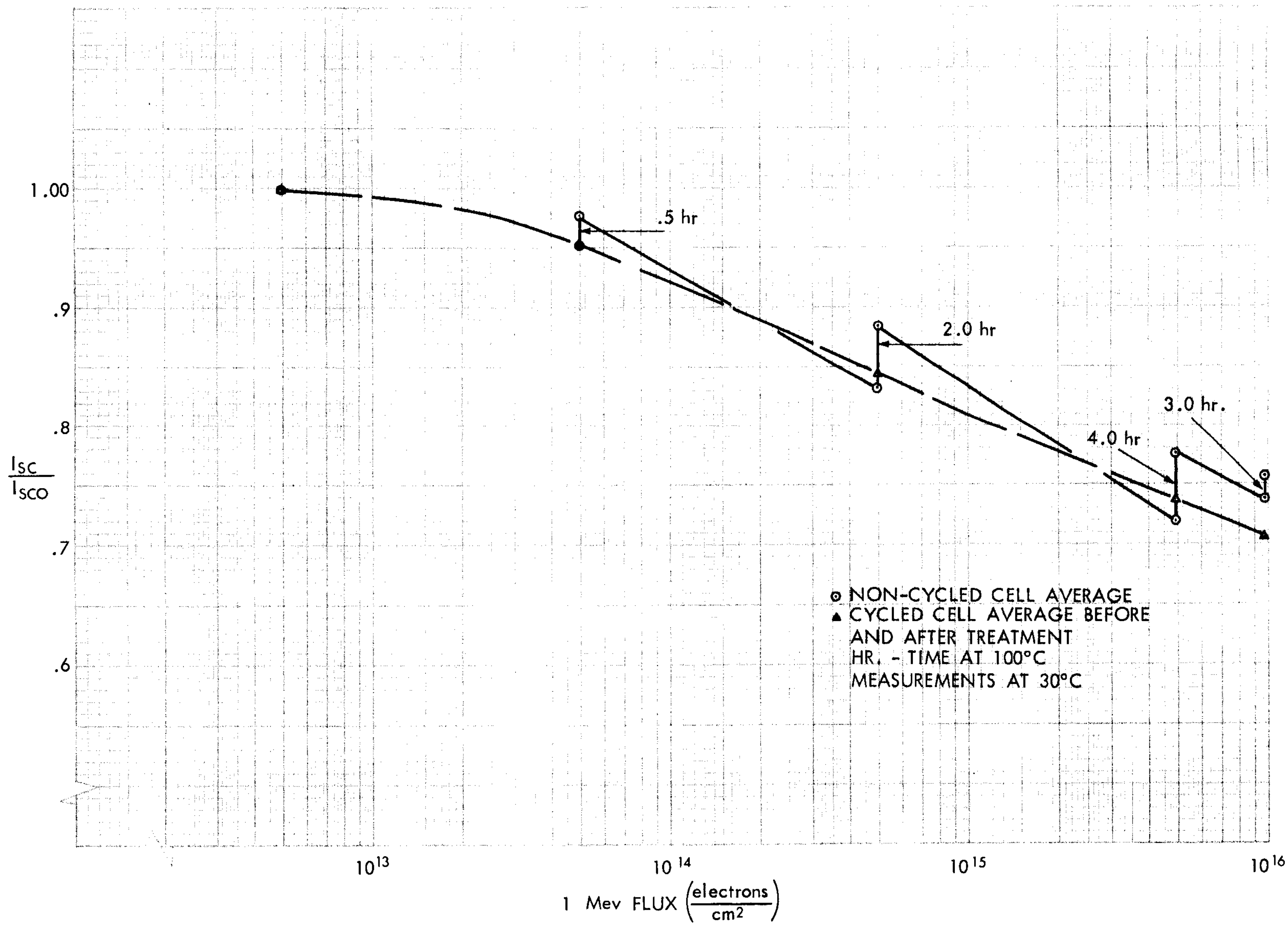

Figure 10 - Effects of Temperature Treatment on Group A Cells

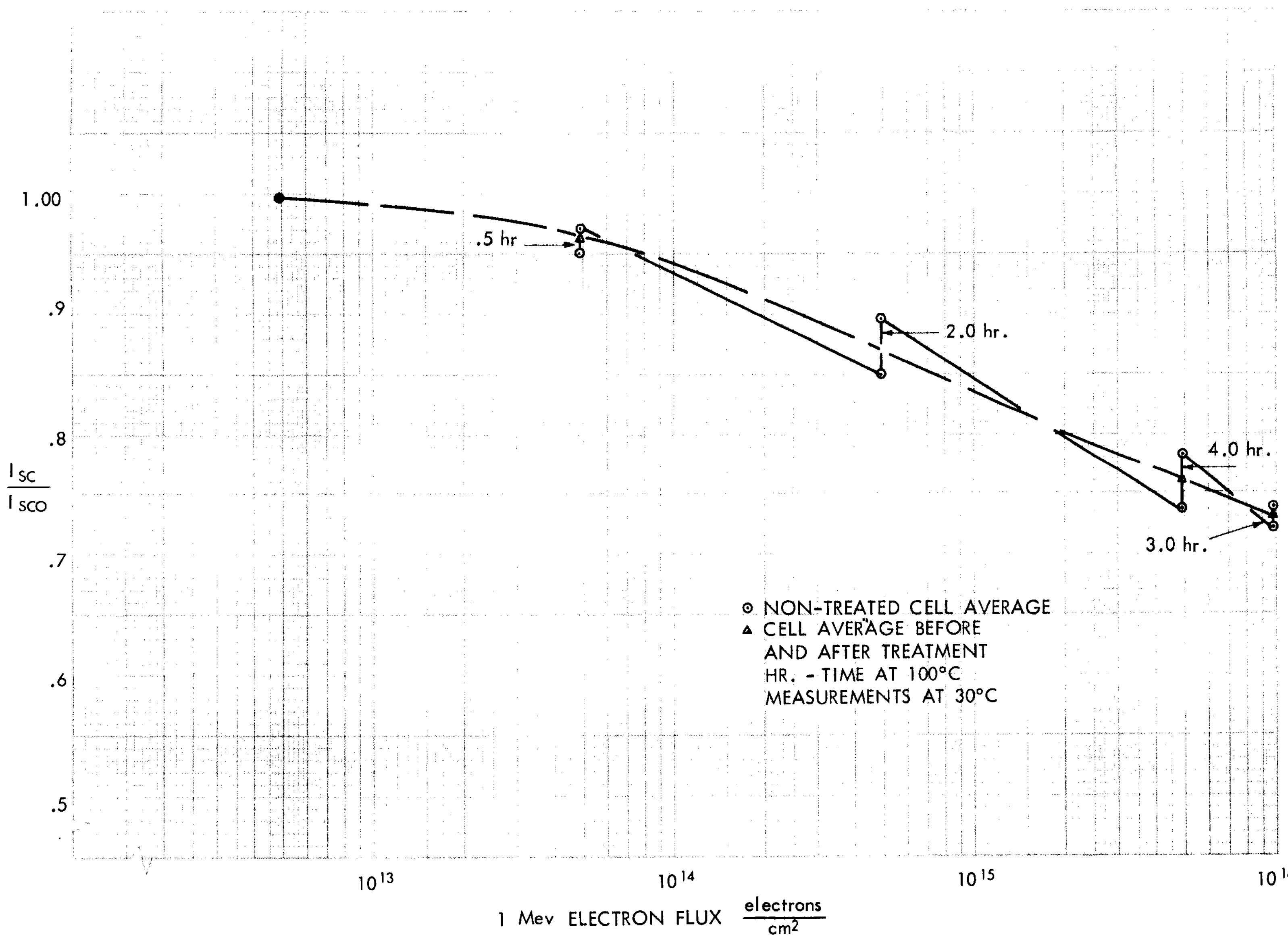

Figure 11 - Effects of Temperature Treatment on Group B Cells

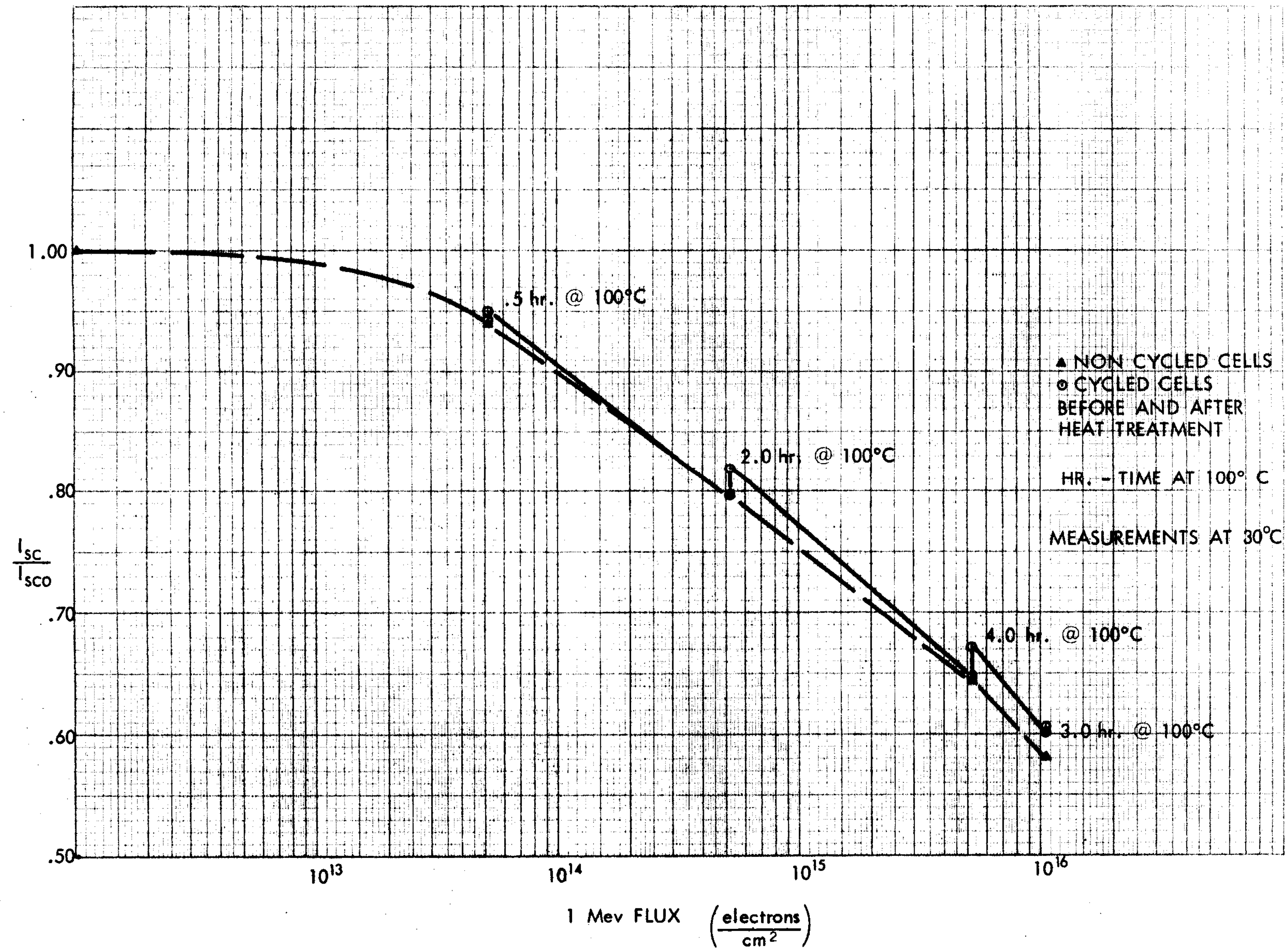

Figure 12 - Effects of Temperature Treatment on C-Cells

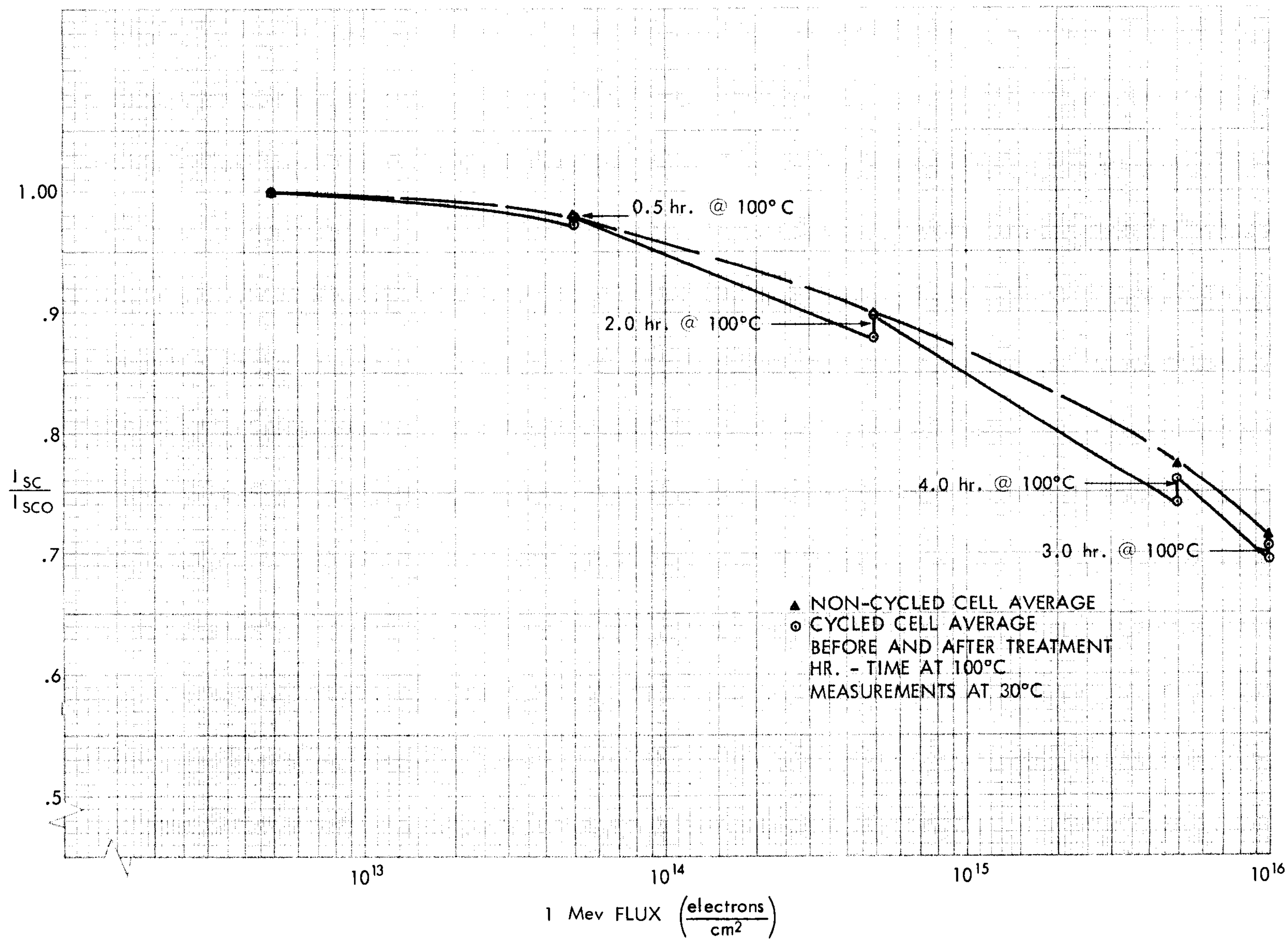

Figure 13 - Effects of Temperature Treatment on D-Cells

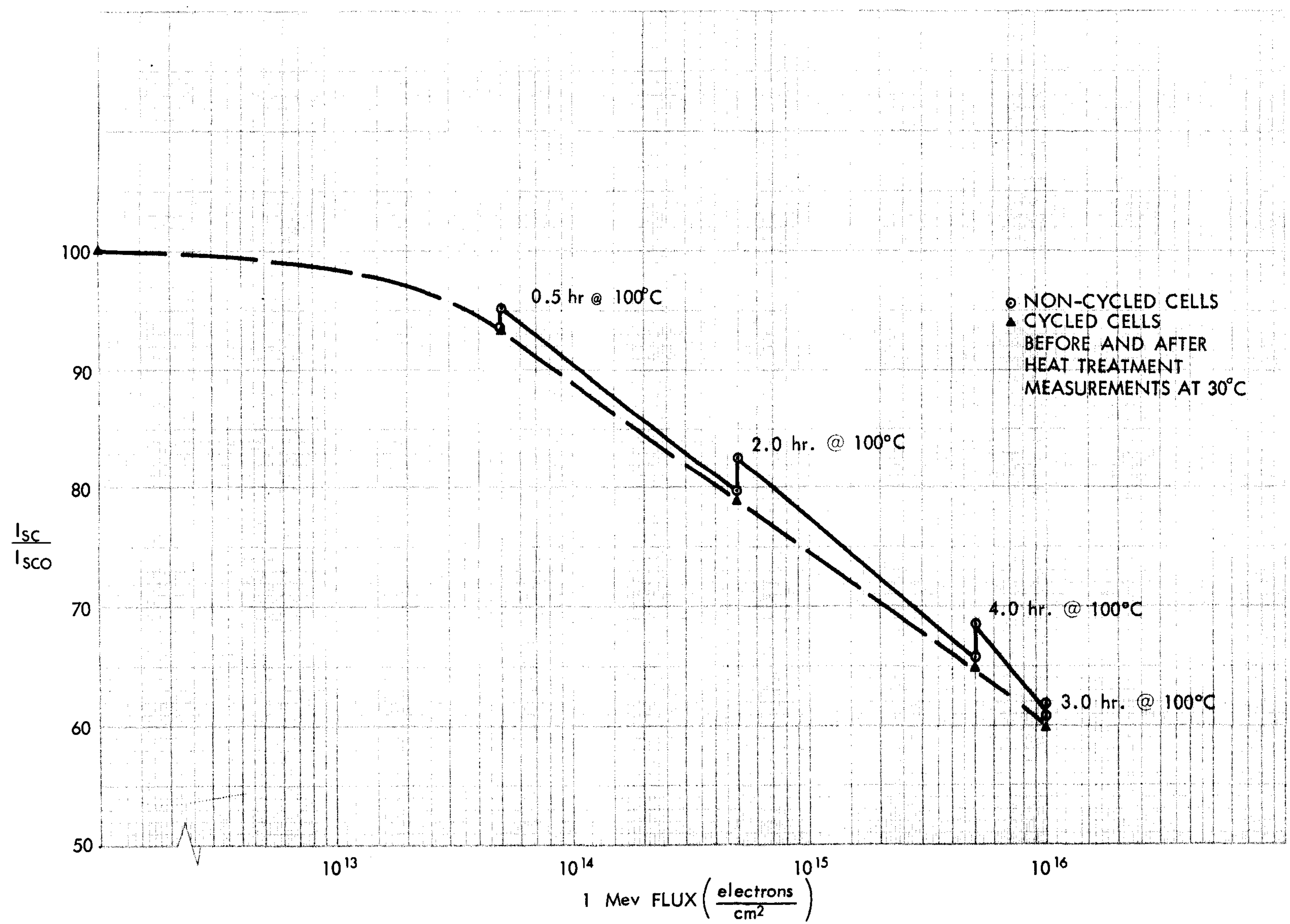

Figure 14 - Effects of Temperature Treatment on E-Cells